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GEOLOGICAL EVOLUTION OF THE OLIGOCENE-MIOCENE BLUFF FORMATION, GRAND CAYMAN

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ABSTRACT

The core of Grand Cayman, like the other Cayman Islands, is formed of dolostones which belong to the Bluff Formation. On Grand Cayman a major disconformity divides it into the lower Cayman Member and the upper Pedro Castle Member.

The Cayman Member is formed of hard, massive, white, microcrystalline dolostone that contains abundant massive and branching corals, bivalves, gastropods, foraminifera, and red algae. This member has high porosity because of (1) leaching of fossils that originally had aragonitic skeletons and (2) dissolution of bedrock associated with karst development. Many of the fossil molds and caves have been partly or totally filled with caymanite (red, white, and black laminated dolostone), fossiliferous grainstone, terra rossa, and/or flowstone.

The disconformity separating the Cayman and Pedro Castle members is a distinct planar surface that was bored by sponges, worms, and bivalves and locally encrusted by red algae. Sedimentological and diagenetic evidence suggest that the Cayman Member was subaerially exposed and subjected to karst development prior to deposition of the Pedro Castle Member. Corals in the upper part of the Cayman Member suggest that it is of early late Oligocene age whereas those in the Pedro Castle Member suggest a middle Miocene age.

The Pedro Castle Member is formed of relatively soft cream to white coloured dolostones that are characterized by abundant foraminifera, rhodolites, and free-living corals. Although porosity is high because of leaching of the corals, there is no evidence of dissolution associated with karst development. Only small amounts of white caymanite are present in a few of the coral molds. Multicoloured caymanite fills some of the westward dipping joints that occur on the south coast between Pedro Castle and Spotts Bay. Although terra rossa occurs in some cavities, no fossiliferous grainstone or flowstone has been found.

Petrographic and geochemical evidence suggest that the original limestones of the Bluff Formation underwent only one phase of pervasive dolomitization. $^{87}\text{Sr}/^{86}\text{Sr}$ isotope ratios suggest that the dolomitization occurred 2 to 5 million years ago.

INTRODUCTION

Matley (1926) originally named the Bluff Limestone for poorly bedded, white to cream coloured, hard, microcrystalline, porous carbonates that formed the core of each of the Cayman Islands (Fig. 1). Although these carbonates have been called limestones (e.g. Mather, 1972; Brunt et al., 1973; Bugg and Lloyd, 1976; Rigby and Roberts, 1976; Stoddart, 1980; Woodroffe et al., 1980; Emery, 1981; Woodroffe, 1981; Woodroffe et al., 1983; Spencer, 1985) recent studies have shown that they are largely dolostone (e.g. Jones et al., 1984; Pleydell, 1987; Pleydell and Jones, 1988; Pleydell et al., in press). Areas of calcareous dolostone or dolomitic limestone are the product of dedolomitization (Jones et al., 1989). Following Jones and Hunter (1989) these strata are referred to as the Bluff Formation because this removes the lithologic connotation associated with the use of the term Bluff Limestone.

The Bluff Formation crops out on the eastern part of Grand Cayman, along a ridge on the southwest coast, and in small outliers at Hell and south of George Town (Fig. 1B). Information on the stratigraphy and sedimentology of the Bluff Formation comes from

scattered coastal outcrops and quarries. A quarry near Pedro Castle (Figs. 1B, 2) contains the type section of the Cayman and Pedro Castle members as designated by Jones and Hunter (1989). There, the members are well exposed along with the disconformity which separates them (Fig. 2).

THE CAYMAN MEMBER

Distribution

The Cayman Member forms most of the Bluff Formation which crops out on Grand Cayman (Fig. 1B) and all of the Bluff Formation on Cayman Brac (Fig. 1C). Preliminary field studies on Little Cayman suggest that it forms all of the Bluff Formation on that island.

Lithology

At its type section in Pedro Castle Quarry, the Cayman Member is formed of two units which Jones and Hunter (1989) designated I and II (Fig. 2A). Unit I, 3 m thick, is a microcrystalline, hard, white dolostone that was originally a packstone to grainstone. Colonial corals (e.g. *Montastrea*, *Leptoceris*, *Agathiphyllia*, *Favia*, *Diploastrea crassolamellata* (Duncan, 1863), *Diploria*), branching corals (e.g. *Stylophora* and *Porites*), gastropods, and rare bivalves occur throughout unit I (Fig. 2A). Many corals were encrusted by red algae. Molds of corals, gastropods, and bivalves contain casts of borings (e.g. *Entobia*, *Trypanites* and *Uniglobites*) such as those described by Pleydell (1987) and Pleydell and Jones (1988). The dolomitized allochems include foraminifera (primarily miliolids), fragments of red algae, *Halimeda*, and echinoid plates and spines. Many echinoid fragments were enlarged by syntaxial overgrowths.

Porosity (up to 25%) and permeability are high in unit I because of leaching of the corals, gastropods, and bivalves. Most pores and cavities in unit I are lined with two types of euhedral dolomite cements (Fig. 2B); type 1 being an inclusion-free, limpid dolomite whereas type 2 is a zoned dolomite (cf. Jones et al., 1984). Many cavities are filled or partly filled with laminated, white caymanite and more rarely red and black caymanite (Fig. 2B).

Filled cavities and caves occur in unit I (Figs. 2A, 2B). Prior to blasting in late 1984 or early 1985, the southwest wall of Pedro Castle Quarry, provided a section through a cave that was 22 m long and 4.5 m high (Jones and Smith, 1988). That cave was filled with caymanite and dolomitized skeletal sands (predominantly foraminifera) overlain by undolomitized flowstone and terra rossa (Lockhart, 1986; Jones and Smith, 1988). This was probably part of a larger cave system.

Unit II (1.75 m thick), formed of white microcrystalline dolostone, contains abundant branching corals (*Stylophora* and *Porites*), rare colonial corals, bivalves, gastropods, rare complete echinoids, and poorly preserved foraminifera (Fig. 2A). The associated sediment was originally a mudstone to wackestone. This unit probably represent thickets of *Stylophora* and *Porites* that promoted deposition of fine grained sediment by baffling currents.

Unit II, like unit I, has high porosity because the corals, gastropods, and bivalves were leached. Casts of borings occur in most corals. Pores and cavities are lined with dolomite cements that are similar to those in unit I. Many cavities are filled or partly

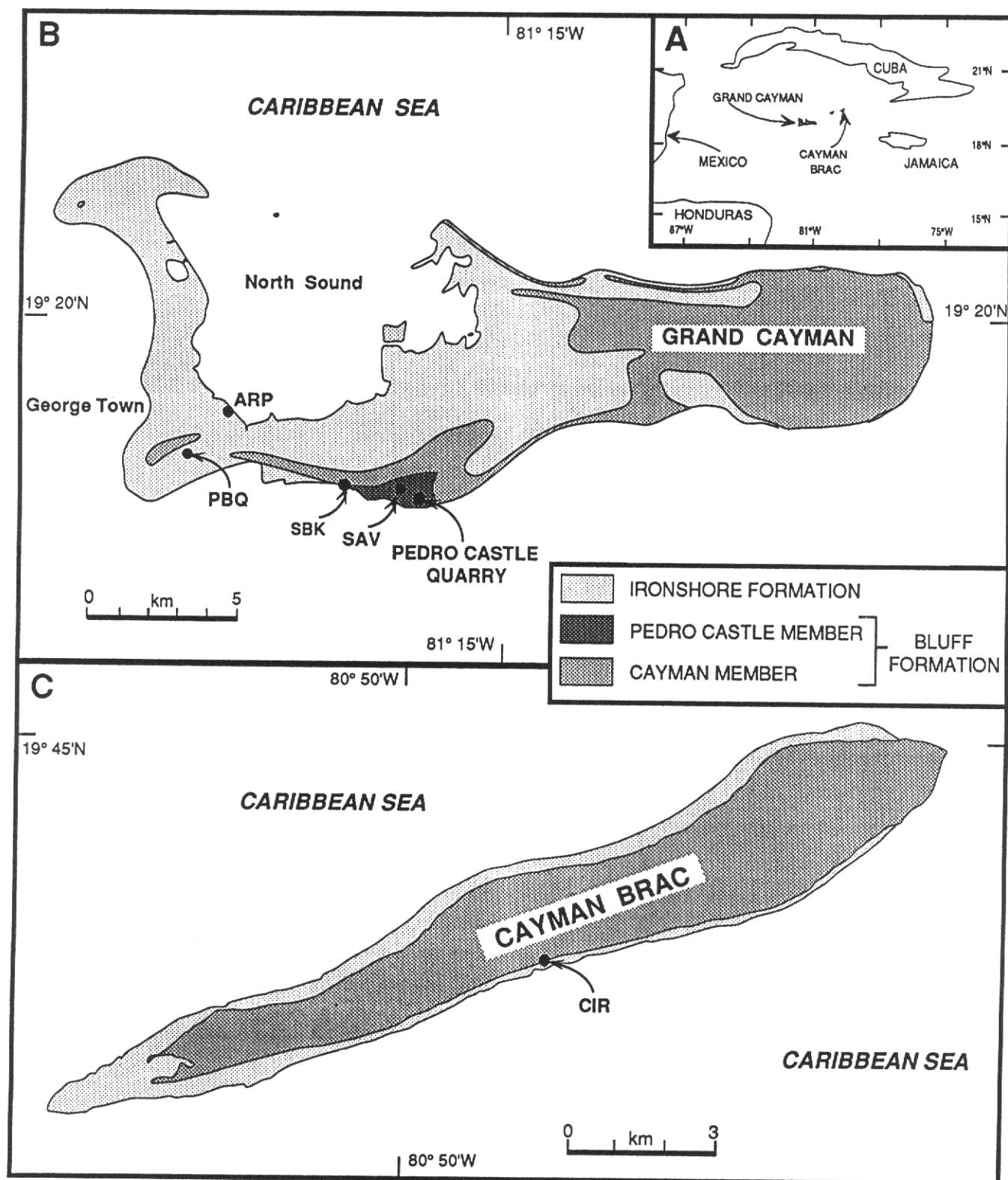


Figure 1. (A) Map of central Caribbean showing positions of Grand Cayman and Cayman Brac. Sketch maps of (B) Grand Cayman and (C) Cayman Brac showing the distribution of the Cayman and Pedro Castle members of the Bluff Formation and Ironshore Formation. ARP = Airport locality; PBQ = Paul Bodden's Quarry; SAV = Savannah; SBK = Spotts Bay; CIR = Cross-island Road

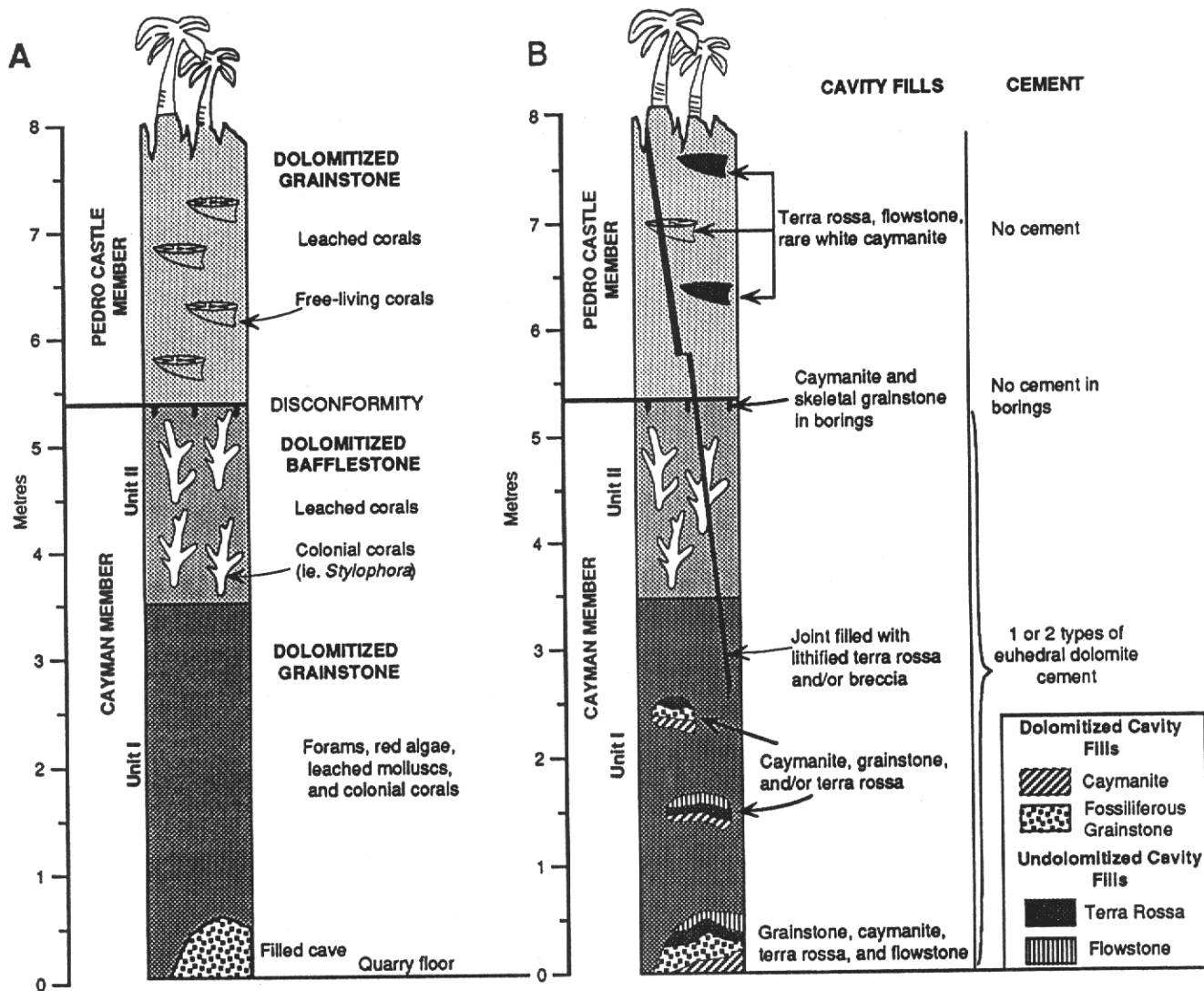


Figure 2. (A) Lithologies and faunal elements, and (B) diagenetic features in the type section of the Bluff Formation in the Pedro Castle Quarry as designated by Jones and Hunter (1989).

filled with laminated, white caymanite, and more rarely red and black caymanite.

Age

Dolostones of the Cayman Member on Cayman Brac contain benthic foraminifera which Vaughan (1926) considered to be of late Oligocene age and correlative with the Antigua Formation on Antigua (Fig. 3). Jones and Hunter (1989), based in part on the coral fauna in the Cayman Member, concluded that it was probably of early late Oligocene age.

THE PEDRO CASTLE MEMBER

Distribution

Besides the type section in Pedro Castle Quarry, the Pedro Castle Member crops out along the south coast between Pedro Castle and Spotts Bay (SBK on Fig. 1). It has also been found in house excavations around Savannah (SAV on Fig. 1) and in the southeast corner of the airport at George Town (ARP on Fig. 1). The former now has houses built on them, whereas the latter was

excavated and material removed during drainage work on the airport.

Lithology

The Pedro Castle Member (Fig. 2A), 2.5 m thick in Pedro Castle Quarry, is formed of off-white to cream coloured, relatively soft (compared to dolostones in the Cayman Member), rubbly weathering dolostone that contains numerous large free-living corals such as *Trachyphyllia*, *Thysanus*, *Teliophyllia*, and *Antillocyathus*. Foraminifera (mostly miliolids), rare fragments of red algae, rare colonial corals, echinoid fragments that lack syntaxial overgrowths, and bivalves also occur. Rhodolites, up to 5 cm in diameter, are common in the basal part of the member. Allochem preservation is poorer than in the Cayman Member. *Entobia* and *Trypanites* casts occur in some corals molds.

Porosity is high in the Pedro Castle Member because the corals, gastropods, and bivalves have been leached. Some fossil molds are lined, partly filled or completely filled with unconsolidated terra rossa (Fig. 2B). The pores or cavities in this member are not lined with dolomite cements. White caymanite and/or

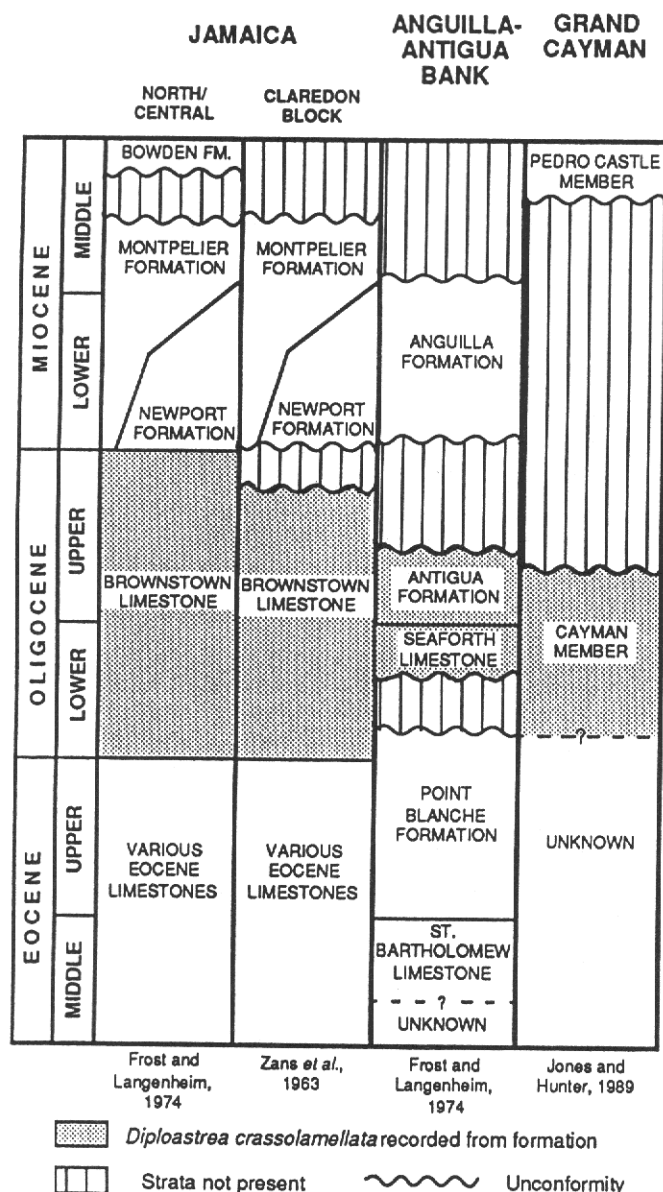


Figure 3. Suggested correlation of the Bluff Formation of Grand Cayman with other Oligocene-Miocene successions on Jamaica and the Anguilla-Antigua Bank.

grainstone are rare, being found in only a few of the hundreds of cavities examined. No red or black caymanite has been found in cavities in this member. On the south coast between Pedro Castle Quarry and Spotts Bay, however, some of the westward dipping joints are filled with white, red, and black caymanite.

Age

Jones and Hunter (1989) suggested that the Pedro Castle Member was of middle Miocene age (Fig. 3) because it contains a coral fauna that (1) is significantly different from that in the underlying Cayman Member, (2) includes the same corals as those from the Bluff Formation around Bodden Town which Matley (1926) considered to be of Miocene age, and (3) is dominated by large free-living corals which are typical of the Miocene in the West Indies (e.g. Frost and Langenheim, 1974; Frost, 1977, p. 96; Vaughan and Hoffmeister, 1926; Vaughan, 1919, p. 212-213).

COMPARISON OF THE CAYMAN AND PEDRO CASTLE MEMBERS

The Cayman Member is distinguished from the Pedro Castle Member because (1) it is massive and hard rather than rubbly and relatively soft (Fig. 4), (2) it is off-white to light grey in colour rather than white to cream in colour (Fig. 4), (3) it contains branching and massive corals rather than large free-living corals (Figs. 2A, 2B, 4), and (4) its cavities contain a wide variety of cements (Fig. 5). In addition, multicoloured caymanite and coarse, dolomitized skeletal grainstone, common in cavities in the Cayman Member are rare in cavities in the Pedro Castle Member (Fig. 2B). Multicoloured caymanite does, however, occur in the westward dipping joints that locally cut the Pedro Castle Member.

DISCONFORMITY BETWEEN THE CAYMAN AND PEDRO CASTLE MEMBERS

In the Pedro Castle Quarry, the contact between the Cayman Member and Pedro Castle Member is a sharply defined disconformity (Figs. 2A, 2B) that contrasts with the vaguely defined bedding that is the norm in the Bluff Formation. The disconformity dips 2° to the northwest in the Pedro Castle Quarry (Jones and Hunter, 1989). *Entobia*, *Uniglobites*, *Trypanites* and *Gastrochaenolites* with their apertures at the disconformity, penetrate into the Cayman Member. These borings, which were probably produced by sponges, worms, and bivalves, are like those which occur in many of the corals in the Bluff Formation (e.g. Pleydell, 1987; Pleydell and Jones, 1988). Such borings could only exist if the upper surface of the Cayman Member was lithified prior to deposition of the overlying Pedro Castle Member.

All borings are filled or partly filled with white, laminated caymanite that is identical to that in cavities in the Cayman Member (Fig. 2B). Partly filled borings display a geopetal fabric with the upper surface parallel to the disconformity. Skeletal sands in the borings contain well preserved foraminifera (miliolids and rare *Lepidocyclina*) and fragments of red algae. Locally, the disconformity surface is encrusted by red algae.

Determining the time period represented by the disconformity between the Cayman and Pedro Castle members is difficult because of the uncertainty regarding the age of the Pedro Castle Member (Jones and Hunter, 1989). Nevertheless, consideration of available evidence suggests that it records a time span of 13 to 14 million years (Jones and Hunter, 1989). A time gap of this magnitude is consistent with the suggestion that the rocks of the Cayman Member underwent considerable diagenetic modification prior to deposition of the Pedro Castle Member.

DIAGENETIC FABRICS IN THE CAYMAN AND PEDRO CASTLE MEMBERS

The Cayman and Pedro Castle members both exhibit a complex array of diagenetic fabrics, including those caused by pervasive dolomitization. Petrographic and geochemical (C, O, and Sr isotopes - Pleydell et al., in press) analyses did not reveal any significant differences between the dolostone of the two members. These data may indicate that the rocks of the Cayman and Pedro Castle members underwent only one phase of dolomitization (Jones et al., 1984; Pleydell, 1987; Jones and Hunter, 1989). Alternatively, the rocks may have been subjected to more than one phase of dolomitization but retained petrographic and geochemical signatures of only the last phase. The lack of dolomite in the overlying Ironshore Formation means that dolomitization of the Bluff Formation must have been completed prior to deposition of that formation approximately 125,000 years ago (Jones et al., 1984; Pleydell, 1987; Jones and Hunter, 1989).

The Bluff Formation on Grand Cayman has undergone a complex paragenetic sequence (Fig. 6) which reflects successive transgressive - regressive cycles and ever changing climatic conditions (Jones and Hunter, 1989). The contrast in the diagenetic fabric of the Cayman Member and the Pedro Castle Member adds further credence to the suggestion that the disconformity between the

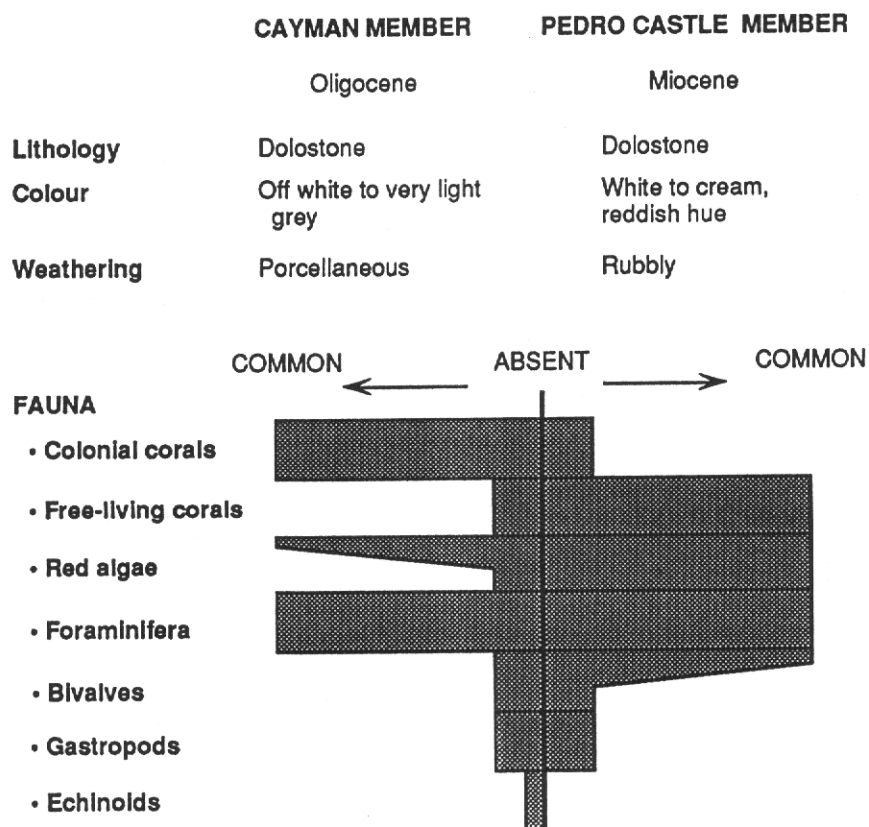


Figure 4. Comparison of depositional features in the Cayman and Pedro Castle members.

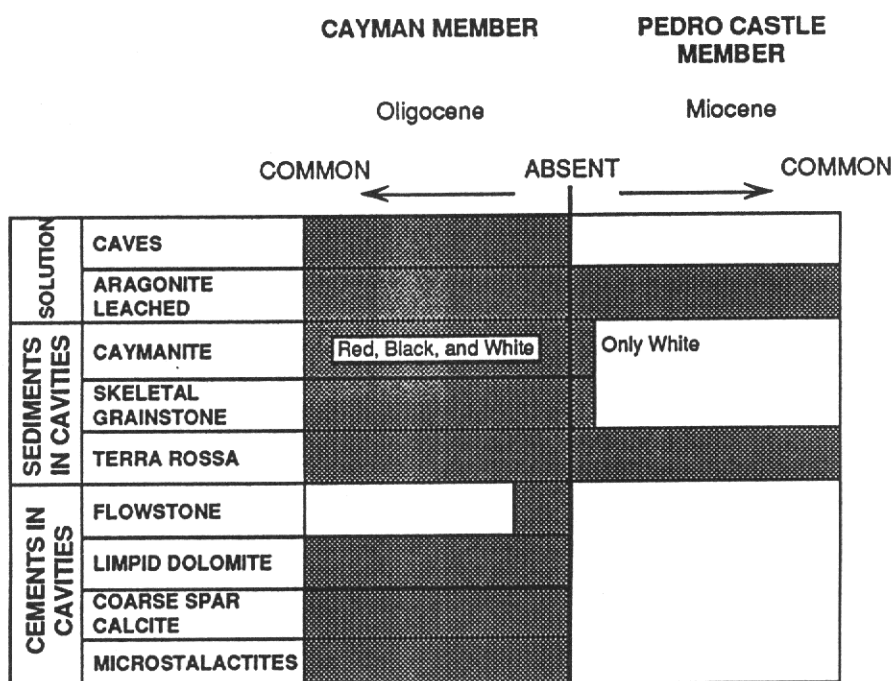


Figure 5. Comparison of diagenetic features in the Cayman and Pedro Castle members.

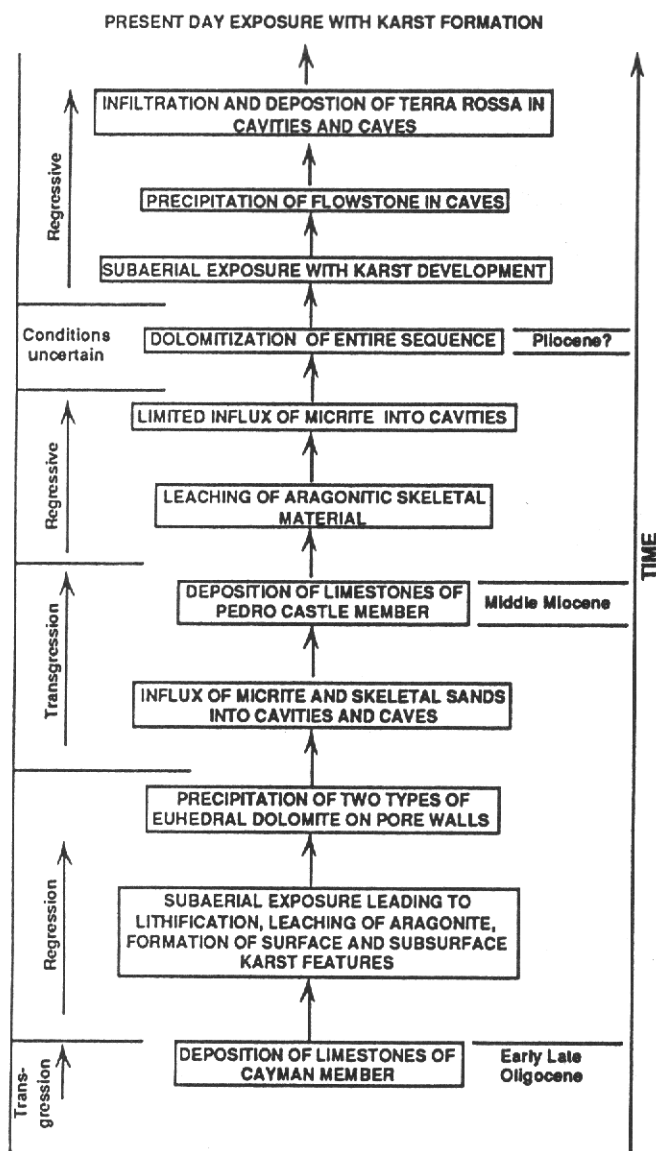


Figure 6. Suggested paragenetic sequence for the Bluff Formation of Grand Cayman.

two members represents a substantial period of time. In this respect, the following comparisons are important:

1. pores and cavities in the Cayman Member are lined with one or two generations of euhedral dolomite cement (cf. Jones et al., 1984) whereas the borings at the disconformity and cavities in the Pedro Castle Member lack these cements (Fig. 2B),
2. multicoloured caymanite is common in cavities throughout the Cayman Member but absent from the Pedro Castle Member apart from rare cavities which contain small amounts of white caymanite (Fig. 3) and westward dipping joints that contain red, white, and black caymanite,
3. caves, cavities, and fossil molds in the Cayman Member are filled or partly filled with multicoloured caymanite, dolomitized skeletal grainstone, flowstone, and terra rossa whereas those in the Pedro Castle Member are either open or contain only minor amounts of white caymanite, flowstone, or terra rossa (Fig. 6).

The contrast in diagenetic styles of the Cayman and Pedro

Castle members suggests that the Cayman Member was lithified prior to deposition of the Pedro Castle Member because (1) the caves, cavities, and moldic porosity could only have maintained their form if the rocks were lithified, (2) the dolomite cements lining the caves, cavities, and fossil molds indicate that the surrounding sediments must have been lithified; if not, the sediment would have collapsed and the cavities destroyed, and (3) the borings at the disconformity could only have been made into lithified sediment.

As in most examples of dolomitization it is difficult to determine the time period during which the original limestones were converted to dolostone. Analysis of 16 samples of dolostone from the Cayman and Pedro Castle members yielded an average $^{87}\text{Sr}/^{86}\text{Sr}$ value of 0.70905. If it is assumed that (1) dolomitization was mediated by seawater, and (2) the $^{87}\text{Sr}/^{86}\text{Sr}$ represents the time of dolomitization (cf. Saller, 1984), the comparison with the $^{87}\text{Sr}/^{86}\text{Sr}$ curve of Koepnick et al. (1985) suggests that dolomitization occurred 2 to 5 million years ago.

CORRELATION OF BLUFF FORMATION BETWEEN GRAND CAYMAN AND CAYMAN BRAC

The Bluff Formation is well exposed on Cayman Brac in steep cliffs that rise to about 50 m above sea level. There is no evi-

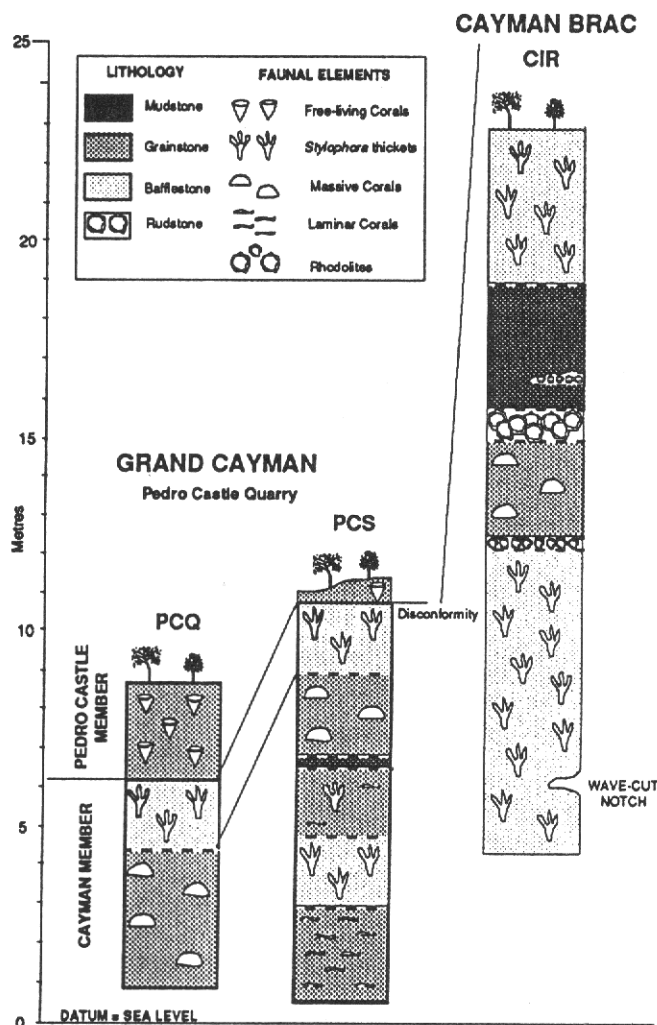


Figure 7. Comparison of the Bluff Formation in Pedro Castle Quarry, Grand Cayman and the south shore of Cayman Brac (locality CIR on Figure 1C).

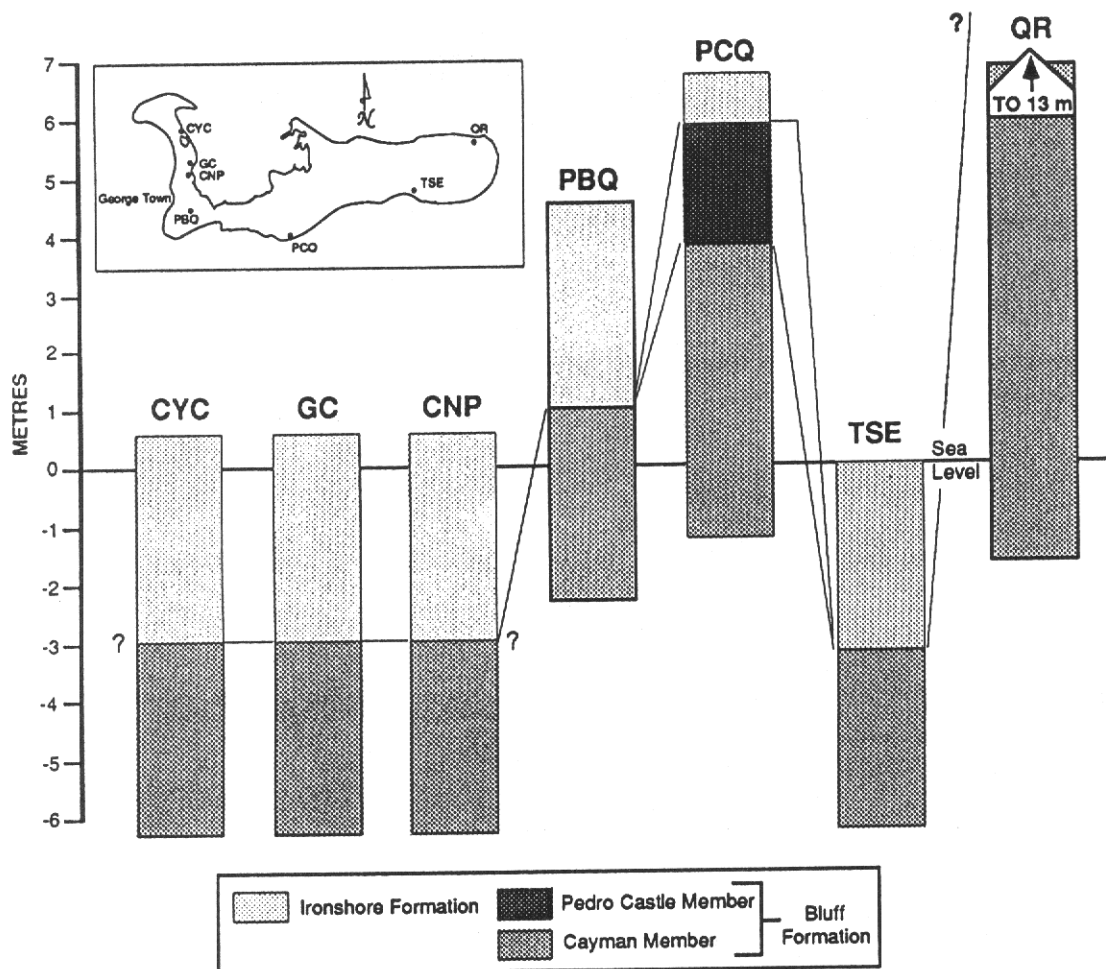


Figure 8. Distribution of the Cayman Member and Pedro Castle Member (Bluff Formation) and the Ironshore Formation relative to present day sea level at selected localities (see inset) on Grand Cayman. CYC = Cayman Yacht Club; GC = Golf Course; CNP = Canal Point; PBQ = Paul Bodden's Quarry; PCQ = Pedro Castle Quarry; TSE = Tarpon Spring Estate; and QR = Queen's Road.

dence of any break in the succession and examination of the dolostones suggest that they all belong to the Cayman Member. In general, the Cayman Member on Cayman Brac appears to encompass a wider range of facies than on Grand Cayman (Fig. 7). With our present state of knowledge it is impossible to accurately correlate the succession on Cayman Brac with the type section on Grand Cayman (Fig. 7) because there are no distinctive units or markers.

DISCUSSION

On Grand Cayman there is considerable evidence that the Bluff Formation has, during the various periods of exposure, been eroded down to different levels (Fig. 8). In the area around Pedro Castle both the Cayman and Pedro Castle members occur. Elsewhere, however, this is not the case. For example, in excavations at Tarpon Springs Estate (TSE - Fig. 8) limestones of the Pleistocene Ironshore Formation rest on dolostones of the Cayman Member. It would appear that the Pedro Castle Member was either never deposited or was removed by erosion prior to deposition of the Ironshore Formation because there is no evidence of the disconformity or the Pedro Castle Member. In a quarry south of George Town (PBQ - Fig. 8) dolostones of the Cayman Member are unconformably overlain by limestones of the Pleistocene Ironshore Formation. The unconformity surface, which has a local relief of up to 1 m, is highlighted by a thin layer of white caymanite and numerous borings (primarily *Entobia*) filled with white caymanite. These features are akin to those which characterize the disconformity that forms the contact between the Cayman and Pedro Castle

members in the quarry near Pedro Castle. Thus, in the quarry near George Town, it is evident that the Pedro Castle Member was completely removed prior to deposition of the Pleistocene Ironshore Formation.

Along Queen's Road (QR - Fig. 8), the Cayman Member is exposed in road cuts that are up to 13 m above sea level. At Canal Point (CNP - Fig. 8), Golf Course (GC - Fig. 8), and the Cayman Yacht Club (CYC - Fig. 8) the contact between the Ironshore Formation and the Bluff Formation is 2 to 4 m below sea level. Dolostones from the upper part of the Bluff Formation are lithologically similar to those from the Cayman Member at its type section.

CONCLUSIONS

Detailed study of the Bluff Formation on Grand Cayman has shown that:

1. it can be divided into the Cayman and Pedro Castle members,
2. the Cayman Member is probably of early late Oligocene age,
3. the Pedro Castle Member is probably of middle Miocene age,
4. the disconformity between the Cayman and Pedro Castle members represents a hiatus of 13 to 14 million years,
5. the diagenetic history of the Cayman Member is different from

that of the Pedro Castle Member,

6. the Cayman Member crops out over most of Grand Cayman whereas the Pedro Castle Member is restricted to scattered remnants that survived post-Miocene erosion,
7. all of the Bluff Formation on Cayman Brac belongs to the Cayman Member.

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